Growth Of Immature Stands Of Ponderosa Pine In The Black Hills

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Rocky Mountain Forest and Range Experiment Station[1]

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CONTENTS

[1] Central headquarters is maintained in cooperation with Colorado State University at Fort Collins; research reported here was conducted in cooperation with South Dakota School of Mines and Technology at Rapid City.

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INTRODUCTION

Expanded precommercial thinning and harvest of roundwood in the Black Hills have increased interest in the effects of density and other stand characteristics on the growth of immature stands. Available information, however, is limited. Meyer (1938) stated that his regional yield tables are probably not applicable to Black Hills conditions. Normally stocked young stands stagnate, hence stand age is not a good indicator of tree size or volume. Also, the yield tables do not indicate possible changes in growth through reduction of stand density. The required information cannot yet be obtained from permanent plots. Data from thinned plots represent only a narrow range of sites, stand diameters, and other characteristics (Myers, 1958). Growth and mortality plots on the Black Hills National Forest were established too recently to provide data for periods of 10 or 20 years.

Until data from permanent plots or yield tables become available, approximate methods of estimating growth must be used. One rapid approximation is a comparison in which past stand measurements and subsequent growth are reconstructed from present stand measurements and increment cores. These values are used to predict the growth of stands now similar to what the reconstructed stands were in the past. Such a method has been developed for immature ponderosa pine (Pinus ponderosa Laws.) in the Black Hills of South Dakota and Wyoming. Changes in diameter, basal area, and volume can be estimated for 10- and 20-year periods by the use of conventional stand measurements.

METHODS USED

Fifty-seven temporary plots were selected in the Black Hills of South Dakota and Wyoming and the Bear Lodge Mountains of Wyoming. Plot sizes varied with tree size and stand density; most had about 150 trees. Even-aged (range 20 years or less) thinned and unthinned stands averaging 3 to 12 inches d.b.h. were sampled in a wide range of site indexes and stand densities and reconstructed to conditions 20 years before measurement, as shown in the following tabulation:

Factor	Range measured
Site index	37 to 73 feet (base 100 years)
Age	31 to 148 years
Trees	202 to 5,575 per acre
Basal area	23 to 234 square feet per acre
Average d.b.h.	1.9 to 10.8 inches
Total cubic feet	115 to 5,210 cubic feet per acre
Merchantable cubic feet	0 to 5,000 cubic feet per acre

Combinations of the variables sampled can be determined by noting the locations of the entries in tables 4 to 9 (see pages 8 to 14). Each plot was carefully checked for uniformity of density, age, and site index. None of the plots had been thinned or otherwise disturbed during the 20-year period preceding measurement.

A complete inventory was made on each plot, and data were obtained for computing the past stand. All trees were bored to determine radial growth at breast height for the past 10 and 20 years. Heights were measured on a sample of the trees and past height growth was determined by boring. The site index of each plot was computed from soil and topography (Myers and Van Deusen, 1960b) to avoid errors due to the effect of stand density on tree height. Average age of the main stand on each plot was determined; occasional small invaders in stands of low density were omitted. Dead trees were measured and classed as having died 0-10, 11-20, or 21+ years ago. Dead trees on permanent plots and in stands thinned at known dates were used as guides in estimating time of death.

Stand tables and height-over-diameter curves were prepared for the present stand and for the stand 10 and 20 years previously. Past diameters outside bark were determined from radial growth, with adjustments for bark growth (Myers and Van Deusen, 1958). Dead trees were included in the appropriate past stand tables. The tables and curves were used to compute current and past basal areas and volumes by 0.1-inch d.b.h. classes.

Total (Myers, 1957) and merchantable (Myers and Van Deusen, 1960a) volumes in cubic feet were computed. Total volumes were the volumes inside bark from ground to tip of all trees. Merchantable volumes were the volumes inside bark from the top of 0.5-foot stumps upward to where diameter inside bark was 4.0 inches. Merchantable volumes were computed for trees 6.0 inches d.b.h. and larger. All stand measures were converted to amounts per acre before further analysis.

Equations for estimating average d.b.h. and other stand variables 10 and 20 years after date of measurement were computed by linear multiple regression with transformation of variables where necessary. The coefficients were tested by analysis of variance and only significant variables were included in the final equations.

RESULTS

Six equations with six tables for predicting diameters, basal areas, and total cubic-foot volumes were computed. Three of each were for stands after 10 years and three for stands after 20 years. Reliability of each regression is indicated by a standard error of estimate (Sy) and a multiple correlation coefficient (R). Conversion factors are presented for computing merchantable cubic-foot and cord volumes from total cubic-foot volumes. Present and future values are for present and future live trees only; mortality is not included. Net periodic increments can be estimated by subtracting present from future diameters, basal areas, or volumes.

DIAMETERS

Average stand d.b.h. in 10 or 20 years can be estimated from present d.b.h., present basal area, and site index (tables 4, 7). Future d.b.h. increases with increase in present d.b.h. and site index. It decreases with increase in present basal area. For this study, a tree of average d.b.h. is a tree of average basal area.

The tables give future diameters for site index 55, the average for the Black Hills. Diameters for other site indexes can be obtained by adding or subtracting the amounts indicated in the table footnotes. Straight-line interpolation for intermediate values of all independent variables will give satisfactory results.

The distribution of diameters in 10 or 20 years can be estimated from the coefficient of variation of diameter. It averages 29 percent in thinned and unthinned stands within the range of average diameters measured. Thus, about 68 percent of the trees will have diameters within $\pm$ 29 percent of average d.b.h. About 95 percent of the tree diameters will be within $\pm$ 58 percent of the average.

BASAL AREAS

Basal area per acre 10 years in the future can be estimated from present basal area, site index, and number of trees per acre (table 5). Stand age should also be used for estimating basal areas 20 years in the future (table 8). Future basal area increases with present basal area, site index, and number of trees per acre. It decreases with increased stand age during a 20-year period.

The tables give future basal areas for site index 55 feet. Basal areas for other site indexes can be determined by using the values given in the table footnotes. Straight-line interpolation may be used for intermediate values of all independent variables.

Although age was not a significant variable for estimating basal areas after 10 years, it is probably a significant factor in basal area growth. Age proved highly significant (1 percent level) for estimating basal area after 20 years. Similar results have been reported for other species.

TOTAL CUBIC VOLUMES

Total cubic-foot volumes after 10 or 20 years can be estimated from present cubic-foot volume, site index, and number of trees per acre (tables 6, 9) Present basal area improves the estimates for periods of 10 years. Future total volume increases with present volume, site index, and number of trees. It decreases with increase in basal area.

Tables 6 and 9 are more complex than the other growth tables because logarithmic values had to be used for three variables. Straight-line interpolation for intermediate values of independent variables will be satisfactory for most purposes. The equations must be solved if greater accuracy is desired.

MERCHANTABLE CUBIC VOLUMES

Present and future merchantable cubic-foot volumes can be computed from present and future total cubic-foot volumes. To do this, determine present and future average d.b.h. and total volume of the stand and obtain the proper ratios from table 1. These ratios express plot volumes in merchantable cubic feet divided by the corresponding volumes in total cubic feet. Multiply the measured or computed total volume by the appropriate ratio to obtain merchantable volume. For example, total volume of a stand averaging 7.0 inches d.b.h. is 3,500 cubic feet per acre. The ratio from table 1 for 7.0 inches is 0.735. The product of 3,500 times 0.735 is 2,572 cubic feet.

Table 1.--Ratios of merchantable cubic-foot to cubic-foot volumes for immature Black Hills ponderosa pine[1]

Average stand d.b.h.	Ratio	Average stand d.b.h.	Ratio
Inches		Inches	
3.0	0.037	8.0	.823
3.5	.085	8.5	.853
4.0	.148	9.0	.881
4.5	.228	9.5	.906
5.0	.335	10.0	.925
5.5	.467	10.5	.942
6.0	.578	11.0	.956
6.5	.671	11.5	.967
7.0	.735	12.0	.976
7.5	.788		

[1] Basis: Plot volumes computed from merchantable (Myers and Van Deusen, 1960a) and total (Myers, 1957) cubic-foot volume tables.

Accuracy of the ratios varies with average d.b.h. of the stand. In stands averaging 3.5 inches or less the ratios may indicate the presence of merchantable volume where none actually exists. This is because the largest tree in one stand may be 5.9 inches, while in a similar stand it is 6.1 inches. One stand has merchantable volume while the other does not, yet both stands can have the same average d.b.h. In the sample plots with trees averaging more than 3.5 inches, the difference between actual and computed merchantable volume was often 1 percent or less of actual volume.

Future merchantable volumes can be computed from equations similar to those presented for total volume. Present merchantable volume, number of trees, and total volume in trees that are expected to grow to 6.0 inches d.b.h. during the period are significant independent variables. Equations solved with these variables, however, gave less accurate estimates of future volumes than the ratios.

CORDWOOD VOLUMES

Present and future cordwood volumes can be computed from corresponding merchantable cubic-foot volumes. Conversion factors have been developed for use with the merchantable cubic-foot volume table used in this study (Woodfin and Landt, 1960). The factors convert cubic volume to standard peeled or unpeeled cords.

To illustrate, let us assume that a stand has an average volume of 2,572 merchantable cubic feet per acre. The conversion factor for unpeeled cords is 76.92. The stand therefore has 2,572 ÷ 76.92 or 33.4 standard cords of unpeeled pulpwood per acre. The factor for peeled wood is 98.39, so the stand has 26.1 peeled cords per acre.

PERIODIC MORTALITY

The number of trees that died in 10 or 20 years was related to the initial number of trees (table 2). The mortality reported represents averages for all plots measured. Some plots differed considerably from the averages.

Table 2.--Decrease in number of trees per acre after 10 and 20 years

Original stand (trees per acre, number)	After 10 years	After 20 years
	Number	Number
200	196	193
300	287	283
400	385	380
600	583	576
800	780	765
1,000	975	950
1,500	1,455	1,345
2,000	1,850	1,670
3,000	2,480	2,165
4,000	2,950	2,520
5,000	3,330	2,815
6,000	3,580	3,065

Mortality was mostly limited to death by suppression of trees in the smallest size classes. The largest measured loss in merchantable volume in 20 years was 209 cubic feet per acre, less than 3 cords. On most of the plots on which the trees averaged 5.4 inches d.b.h. or larger, loss was less than 1 cord in 20 years. No merchantable cubic-foot volume was lost on plots where the trees averaged less than 5.4 inches d.b.h.

Determination of mortality is an important source of error in studies of this type. The slow rate of decay in the Black Hills aided mortality estimation. Numerous areas thinned at known dates were available as study plots or to provide guides for dating time of death of trees on the study plots. Cut living and dead stems had been piled or laid perpendicular to the contour so trees that died and fell over after thinning were readily located. Suitable reconstructions of past stand tables could therefore be made.

APPLICATION

This method can be used to estimate the future characteristics of a stand or to compare potential results from alternate methods of treatment. For example, a stand now has the measurements given in column 2 of table 3. The stand may be thinned or left unthinned. If left unthinned, the stand after 10 years will have the measurements given in column 4 of the table. Thinning to 80 square feet of basal area might convert the present stand to one having the values shown in column 3. After 10 years the thinned stand would have the characteristics shown in column 5. With this information a land manager is in a better position to decide whether or not to thin to produce the product desired.

Table 3. --Present and future stands per acre with two alternative methods of treatment

Measure	Present amounts		Amounts in 10 years	
	Unthinned	Thinned	Unthinned	Thinned
Site index	55	55	55	55
D.b.h., inches	5.0	6.5	5.7	7.5
Basal area, square feet	170	80	187	104
Number of trees	1,250	347	1,220	335
Total cubic feet	2,000	1,000	2,464	1,528
Merchantable cubic feet	670	670	1,269	1,204
Unpeeled cords	8.7	8.7	16.5	15.7

The characteristics of a stand after cutting can be determined by marking the stand for cutting and measuring the unmarked trees. Data from thinning studies (Myers, 1958) can be used to estimate changes due to thinning if information based on local practice is available. Better initial data will be obtained if thinnings are subtracted from present stand tables and diameters, basal areas, and volumes are computed from the adjusted tables.

The equations and other prediction aids are intended for use only with existing stands within the range of variables sampled. Black Hills stands have suffered periods of suppression during their development. It is not known how well the equations will apply to stands that have not suffered similar periods of suppression. Extension of the results beyond the ranges of the variables sampled could result in errors. The possible magnitude of the errors cannot be foretold.

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Tables for estimating average d.b.h., basal areas, and total cubic-foot volumes after 10 and 20 years.

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Table 4.--Average d.b.h. after 10 years, immature Black Hills ponderosa pine,[1] site index 55 feet[2]

D.b.h. at beginning of period (Inches)	Basal area at beginning of period, square feet per acre							
	30	50	80	110	140	170	200	230
	D.b.h. after 10 years, inches							
2.0	3.3	3.1	2.9	2.7	2.6	2.5	2.5	2.4
3.0	4.3	4.1	3.9	3.8	3.7	3.6	3.5	3.5
4.0	5.4	5.2	5.0	4.8	4.7	4.7	4.6	--
5.0	--	6.2	6.0	5.9	5.8	5.7	5.6	--
6.0	--	7.2	7.0	6.9	6.8	6.7	--	--
7.0	--	8.2	8.0	7.9	7.8	7.7	--	--
8.0	--	9.2	9.0	8.8	8.7	8.6	--	--
9.0	--	10.1	9.9	9.8	9.7	9.6	--	--
10.0	--	11.0	10.8	10.7	10.6	10.5	--	--
11.0	--	11.9	11.7	11.6	11.5	11.4	--	--

[1] From equation:

$$Y = 1.57 + 1.131 X_1 - 0.011 X_1^2 - 0.966 \log X_2 + 0.016 X_3$$

Where: Y = Average d.b.h. in 10 years

X_1 = Present average d.b.h.

X_2 = Present basal area per acre

X_3 = Site index

$R = 0.9952$

$S_y = 0.1941$ inch

[2] Add 0.1 inch for each 5 feet above 55, subtract 0.1 inch for each 5 feet below.

Table 5.--Basal area per acre after 10 years, immature Black Hills ponderosa pine,[1] site index 55 feet[2]

Number trees at beginning of period	Basal area at beginning of period, square feet per acre							
	30	50	80	110	140	170	200	230
	Basal area after 10 years, square feet							
200	54	70	94	118	--	--	--	--
400	65	82	106	130	155	179	--	--
600	69	85	110	134	158	183	--	--
800	71	87	112	136	160	185	--	--
1,000	72	89	113	137	162	186	--	--
1,500	74	90	114	139	163	187	--	--
2,000	--	91	115	140	164	188	213	--
3,000	--	--	116	140	165	189	213	--
4,000	--	--	--	--	165	189	214	--
5,000	--	--	--	--	165	190	214	238
6,000	--	--	--	--	166	190	214	238

[1] From equation:

$$Y = 26.51 + 0.811\, X_1 + 0.477\, X_2 - 4709.26/X_3$$

Where: Y = Basal area in 10 years

X_1 = Present basal area

X_2 = Site index

X_3 = Number of trees per acre

$R = 0.9833$

$Sy = 8.07$ square feet

[2] Add 2.4 square feet for each 5 feet above 55, subtract 2.4 square feet for each 5 feet below.

Table 6.--Total cubic feet per acre after 10 years, immature Black Hills ponderosa pine[1]

Site index	Present total cubic feet	Basal area 30						Basal area 80						Basal area 130						Basal area 180						Basal area 230		
		Trees per acre						Trees per acre						Trees per acre						Trees per acre						Trees per acre		
		200	400	700	1000	3000	5000	200	400	700	1000	3000	5000	200	400	700	1000	3000	5000	200	400	700	1000	3000	5000	1000	3000	5000
Feet		Cubic feet						Cubic feet						Cubic feet						Cubic feet						Cubic feet		
40	200	--	485	509	519	--	--	--	432	453	462	--	--	--	384	403	411	--	--	--	--	358	365	--	--	--	--	--
	400	689	771	809	824	849	--	613	686	720	733	773	--	545	610	640	653	672	--	--	--	569	580	598	--	--	--	--
	600	928	1038	1089	1110	1143	--	825	923	968	987	1017	--	734	821	862	878	905	--	--	--	766	781	805	--	--	--	--
	800	1159	1296	1360	1386	1428	--	1031	1153	1210	1233	1271	--	917	1026	1076	1097	1130	--	--	--	958	976	1006	--	--	--	--
	1000	1387	1551	1627	1659	1709	1719	1234	1380	1448	1476	1521	1530	1097	1228	1288	1313	1353	1361	--	--	1146	1168	1203	1211	--	--	--
	1200	1613	1804	1892	1929	1988	2000	1435	1605	1684	1716	1768	1779	1276	1428	1498	1527	1573	1583	--	--	1332	1358	1399	1408	--	--	--
	1500	1950	2181	2289	2333	2404	2418	1735	1941	2036	2076	2138	2151	1544	1726	1811	1846	1902	1914	--	--	1611	1643	1692	1703	--	--	--
	2000	2514	2812	2950	3007	3098	3117	2236	2501	2624	2675	2756	2773	--	2225	2335	2380	2452	2467	--	--	--	2117	2181	2195	--	--	--
	2500	3081	3447	3616	3686	3798	3821	2741	3066	3217	3279	3379	3399	--	2728	2862	2917	3006	3024	--	--	--	2595	2674	2690	--	--	--
	3000	3655	4088	4289	4372	4505	4532	3252	3637	3816	3890	4008	4032	--	3236	3395	3460	3565	3587	--	--	--	3078	3172	3191	--	--	--
50	200	--	528	553	564	--	--	--	469	492	502	--	--	--	417	438	447	--	--	--	371	390	397	--	--	--	--	--
	400	749	838	879	896	923	--	667	746	782	797	822	--	593	663	696	709	731	--	528	590	619	631	650	--	--	578	--
	600	1008	1128	1183	1206	1243	--	897	1004	1053	1073	1106	--	798	893	937	955	984	--	710	794	833	849	875	--	--	779	--
	800	1260	1409	1479	1507	1553	--	1121	1254	1315	1341	1381	--	997	1115	1170	1193	1229	--	887	992	1041	1061	1093	--	--	973	--
	1000	1508	1686	1769	1803	1858	1869	1341	1500	1574	1604	1653	1663	1193	1334	1400	1427	1470	1479	1061	1187	1246	1270	1308	1316	--	1164	1171
	1200	1753	1961	2057	2097	2161	2174	1560	1744	1830	1866	1922	1934	1387	1552	1628	1660	1710	1720	--	1381	1449	1477	1521	1530	--	1353	1362
	1500	2120	2372	2488	2536	2613	2629	1886	2110	2214	2256	2325	2339	1678	1877	1969	2007	2068	2081	--	1670	1752	1786	1840	1851	--	1637	1647
	2000	2733	3057	3207	3269	3368	3388	2431	2719	2853	2908	2996	3014	2163	2419	2538	2587	2666	2682	--	2152	2258	2302	2372	2386	--	2110	2122
	2500	3350	3747	3931	4007	4129	4154	2980	3333	3497	3565	3673	3695	2651	2965	3111	3171	3268	3287	--	--	2768	2821	2907	2924	--	2586	2602
	3000	3973	4444	4663	4753	4897	4927	3535	3954	4148	4229	4357	4383	3145	3517	3690	3762	3876	3899	--	--	3283	3347	3448	3469	--	3067	3086

60	200	--	565	593	604	--	--	--	502	527	537	--	--	--	447	469	478	--	--	--	398	417	425	--	--	378	--	--
	400	802	897	941	960	989	--	714	798	837	854	880	--	635	710	745	759	782	--	565	632	663	676	696	--	601	619	--
	600	1080	1208	1267	1292	1331	--	961	1074	1127	1149	1184	--	854	956	1003	1022	1053	--	760	850	892	909	937	--	809	834	--
	800	1349	1509	1583	1614	1662	--	1200	1342	1408	1436	1479	--	1068	1194	1253	1277	1316	--	950	1062	1114	1136	1171	--	1011	1041	--
	1000	1614	1805	1894	1931	1989	2001	1436	1606	1685	1718	1770	1780	1277	1429	1499	1528	1574	1584	1136	1271	1334	1359	1401	1409	1209	1246	1253
	1200	1877	2099	2203	2245	2313	2327	1670	1868	1960	1997	2058	2070	1485	1662	1743	1777	1831	1842	1322	1478	1551	1581	1629	1639	1406	1449	1458
	1500	2270	2539	2664	2715	2798	2814	2019	2259	2370	2416	2489	2504	1796	2009	2108	2149	2214	2227	1598	1788	1876	1912	1970	1982	1701	1752	1763
	2000	2926	3272	3433	3500	3606	3628	2603	2911	3054	3114	3208	3227	2315	2590	2717	2770	2854	2871	2060	2304	2417	2464	2539	2554	2192	2259	2272
	2500	3586	4011	4209	4290	4420	4447	3191	3569	3744	3817	3932	3956	2838	3175	3331	3395	3498	3519	--	2824	2963	3021	3112	3131	2687	2769	2785
	3000	4254	4758	4992	5089	5243	5275	3784	4233	4441	4527	4664	4692	3367	3766	3951	4027	4150	4174	--	3350	3515	3583	3692	3714	3187	3284	3304
70	200	--	598	628	640	--	--	--	532	558	569	--	--	--	474	497	506	--	--	--	421	442	450	--	--	401	--	--
	400	850	950	997	1017	1047	--	756	846	887	904	932	--	673	752	789	804	829	--	598	669	702	716	737	--	637	656	--
	600	1144	1279	1342	1368	1410	--	1018	1138	1194	1217	1254	--	905	1013	1062	1083	1116	--	805	901	945	963	993	--	857	883	--
	800	1429	1598	1677	1709	1761	--	1271	1422	1492	1521	1567	--	1131	1265	1327	1353	1394	--	1006	1125	1181	1204	1240	--	1071	1103	--
	1000	1710	1912	2006	2045	2107	2120	1521	1701	1785	1820	1875	1886	1353	1514	1588	1619	1668	1678	1204	1346	1413	1440	1484	1493	1281	1320	1328
	1200	1988	2224	2333	2379	2451	2465	1769	1979	2076	2116	2180	2193	1574	1760	1847	1882	1940	1951	1400	1566	1643	1675	1725	1736	1490	1535	1544
	1500	2405	2690	2822	2877	2964	2982	2139	2393	2510	2559	2637	2653	1903	2129	2233	2277	2346	2360	1693	1894	1987	2025	2087	2099	1802	1856	1868
	2000	3099	3467	3637	3708	3820	3843	2757	3084	3236	3298	3398	3419	2453	2744	2879	2934	3023	3041	2182	2441	2561	2610	2690	2706	2322	2393	2407
	2500	3799	4250	4459	4545	4683	4711	3380	3781	3967	4043	4166	4191	3007	3363	3529	3597	3706	3728	2675	2992	3139	3200	3297	3317	2847	2933	2951
	3000	4507	5041	5289	5391	5554	5588	4009	4484	4705	4796	4941	4971	3567	3989	4186	4267	4396	4422	3173	3549	3724	3796	3911	3934	3377	3479	3500
	4000	5947	6652	6979	--	--	--	5291	5918	6209	--	--	--	4707	5264	--	--	--	--	4187	4684	--	--	--	--	--	--	--
	5000	7425	8305	8713	--	--	--	6605	7388	7751	--	--	--	5876	6572	--	--	--	--	5228	5847	--	--	--	--	--	--	--

[1] From equation:

$$\text{Log } Y = 1.444 + 0.136 (\log X_1)^2 + 0.374 \log X_2 - \frac{19.456}{X_3} - 0.001 X_4$$

Where: Y = Cubic feet in 10 years

X_1 = Present cubic feet

X_2 = Site index

X_3 = Number of trees

X_4 = Basal area

$R = 0.9924$ $\qquad$ Sy = 8 percent at mean cubic feet

Table 7.--Average d.b.h. after 20 years, immature Black Hills ponderosa pine,[1] site index 55 feet[2]

D.b.h. at beginning of period (Inches)	Basal area at beginning of period, square feet per acre							
	30	50	80	110	140	170	200	230
	D.b.h. after 20 years, inches							
2.0	4.1	3.8	3.5	3.3	3.1	3.0	2.9	2.8
3.0	5.3	5.0	4.7	4.4	4.3	4.2	4.0	3.9
4.0	6.4	6.1	5.8	5.5	5.4	5.3	5.1	--
5.0	--	7.2	6.9	6.6	6.5	6.4	6.2	--
6.0	--	8.2	7.9	7.7	7.5	7.4	--	--
7.0	--	9.2	8.9	8.7	8.5	8.4	--	--
8.0	--	10.1	9.8	9.6	9.4	9.3	--	--
9.0	--	11.0	10.7	10.5	10.3	10.2	--	--
10.0	--	11.9	11.6	11.4	11.2	11.1	--	--
11.0	--	12.8	12.4	12.2	12.0	11.9	--	--

[1] From equation:

$$Y = 2.431 + 1.268 X_1 - 0.021 X_1^2 - 1.540 \log X_2 + 0.028 X_3$$

Where: Y = Average d.b.h. in 20 years

X_1 = Present average d.b.h.

X_2 = Present basal area per acre

X_3 = Site index

$R = 0.9855$

$Sy = 0.3482$ inch

[2] Add 0.3 inch for each 10 feet above 55, subtract 0.3 inch for each 10 feet below.

Table 8. --Basal area per acre after 20 years, immature Black Hills ponderosa pine,[1] site index 55 feet[2]

Stand age (Years)	Number of trees at beginning of period	Basal area at beginning of period, square feet					
		30	50	80	110	140	170
		- Basal area after 20 years, square feet -					
30	200	88	--		--	--	--
	400	106	122	--	--	--	--
	600	112	127	--	--	--	--
	800	115	130	154	--	--	--
	1,000	116	132	156	--	--	--
	1,500	119	134	158	182	--	--
	2,000	--	136	159	183	--	--
	3,000	--	137	160	184	--	--
	4,000	--	137	161	184	--	--
	5,000	--	138	161	185	--	--
	6,000	--	138	161	185	--	--
60	200	74	90	113	--	--	--
	400	91	107	131	154	178	--
	600	97	113	136	160	184	--
	800	100	116	139	163	186	210
	1,000	102	117	141	165	188	212
	1,500	104	120	143	167	190	214
	2,000	--	121	144	168	192	215
	3,000	--	--	--	--	193	216
	4,000	--	--	--	--	193	217
	5,000	--	--	--	--	194	217
	6,000	--	--	--	--	194	218
90	200	--	81	105	128	152	175
	400	--	98	122	146	169	193
	600	--	--	128	151	175	199
	800	--	--	131	154	178	201
	1,000	--	--	--	--	180	203
	1,500	--	--	--	--	--	206
120	200	--	75	98	122	146	169
	400	--	92	116	139	163	187
	600	--	--	122	145	169	192
	800	--	--	--	148	172	195
	1,000	--	--	--	--	174	197
	1,500	--	--	--	--	--	199

[1] From equation:

$$Y = 132.14 + 0.786\ X_1 + 0.715\ X_2 - 48.592 \log X_3 - 6971.52/X_4$$

Where: Y = Basal area in 20 years

X_1 = Present basal area

X_2 = Site index

X_3 = Age

X_4 = Number of trees per acre

R = 0.9690

Sy = 10.73 square feet

[2] Add 7 square feet for each 10 feet above 55, subtract 7 square feet for each 10 feet below.

Table 9. --Total cubic feet per acre after 20 years, immature Black Hills ponderosa pine[1]

Site index (Feet)	Present cubic feet per acre	Present number of trees per acre: 200	400	700	1,000	3,000	5,000
		Cubic feet per acre					
40	200	--	883	914	927	--	--
	400	1,080	1,172	1,214	1,231	1,258	--
	600	1,295	1,405	1,455	1,476	1,509	--
	800	1,484	1,610	1,668	1,691	1,729	--
	1,000	1,656	1,797	1,861	1,888	1,929	1,938
	1,200	1,816	1,971	2,041	2,070	2,116	2,125
	1,500	2,040	2,214	2,293	2,325	2,377	2,387
	2,000	2,383	2,586	2,678	2,716	2,776	2,788
	2,500	--	2,929	3,033	3,076	3,144	3,158
50	200	--	1,018	1,055	1,070	--	--
	400	1,245	1,352	1,400	1,420	1,451	--
	600	1,494	1,621	1,679	1,703	1,740	--
	800	1,712	1,858	1,924	1,951	1,994	--
	1,000	1,910	2,073	2,147	2,177	2,225	2,235
	1,200	2,095	2,274	2,355	2,388	2,441	2,451
	1,500	2,353	2,554	2,645	2,682	2,742	2,754
	2,000	2,749	2,983	3,089	3,133	3,202	3,216
	2,500	3,113	3,379	3,499	3,549	3,627	3,643
	3,000	3,456	3,750	3,884	3,939	4,026	4,044
60	200	--	1,144	1,185	1,202	--	--
	400	1,400	1,519	1,573	1,595	1,630	--
	600	1,679	1,822	1,887	1,913	1,955	--
	800	1,923	2,087	2,162	2,192	2,241	--
	1,000	2,147	2,330	2,413	2,447	2,501	2,512
	1,200	2,354	2,555	2,646	2,684	2,743	2,755
	1,500	2,645	2,870	2,972	3,014	3,081	3,094
	2,000	3,089	3,352	3,472	3,521	3,598	3,614
	2,500	3,498	3,797	3,932	3,988	4,076	4,093
	3,000	3,884	4,215	4,365	4,427	4,524	4,544
70	200	--	1,263	1,308	1,327	--	--
	400	1,545	1,676	1,736	1,761	1,800	--
	600	1,853	2,010	2,082	2,112	2,158	--
	800	2,123	2,304	2,386	2,420	2,473	--
	1,000	2,369	2,571	2,663	2,700	2,760	2,772
	1,200	2,598	2,820	2,920	2,962	3,027	3,040
	1,500	2,919	3,168	3,281	3,327	3,400	3,415
	2,000	3,409	3,700	3,832	3,886	3,971	3,989
	2,500	3,861	4,190	4,340	4,401	4,498	4,518
	3,000	4,286	4,652	4,818	4,886	4,993	5,015
	4,000	5,079	5,512	--	--	--	--
	5,000	5,817	6,313	--	--	--	--

[1] From equation:

$$\text{Log } Y = 1.515 + 0.083\,(\log X_1)^2 + 0.640 \log X_2 - \frac{14.212}{X_3}$$

Where: Y = Total cubic feet per acre in 20 years

X_1 = Present cubic feet

X_2 = Site index

X_3 = Number of trees

$R = 0.9669$ S_y = 13 percent at mean cubic feet

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